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BP Cherry Point Cogen
DEIS Comment - 12

October 22, 2003

Mr. Allen Fiksdal, Manager
Energy Facility Site Evaluation Council
P.O. Box 43172
Olympia, WA 98504-3172

Dear Mr. Fiksdal,

I submit that Natural gas-fired power plants are a potent source of extremely hazardous health risk with tiny particles 2.5 microns or less in diameter (PM2.5). All of the particulate matter produced by the gas-fired turbines of power plants will be less than 2.5 microns in diameter. In fact, all of it will be less than 1 micron in diameter, and consist largely of organic compounds referred to as products of incomplete combustion. Hazardous trace metals plus SO4, NH4 and NO3 will also be released. The EPA has been studying PM2.5 for some time, which lead the agency to propose new standards for exposure and emissions. I am enclosing a copy of Particulate Matter Research Program Strategy, which describes the EPA's work in the areas of health and exposure. 1

Many medical studies link PM2.5 or particulate matter to heart attacks and deaths. There will be severe health implications for us at Birch Bay as this natural gas-fired power plant commences spewing hundreds of tons of PM2.5 and ammonium sulfate annually. 2 In addition, have you added what the existing cogeneration plant pollutes to what the proposed new one will add? 3

Noise is an additional concern. The BP plant is very noisy today, keeping me awake at night. Sometimes it is quite and I can sleep. This new cogeneration plant will make noise 24 hours a day. That is not acceptable for the residents of Birch Bay. Also, have you considered what the new plant noise will be along with the noise of the proposed pipeline to go under Georgia Strait from Cherry Point? 4

If you approve the site, it should be as far in the southeast corner of the BP facility as possible, away from the Birch Bay population. You should however, not approve such a huge monster and only give BP a cogeneration plant for their refinery requirements. Power plants of this large magnitude should not be located around population centers. There is plenty of space in this county to locate the plant away from people! Plus you would be contributing to ruining one of the great recreation areas of our state. 5

I strongly urge you not to approve the proposed plant. As you can read in the EPA study, you will be causing health problems and will be signing the death warrant of many seniors and children.

Sincerely,

Arne R. Cleveland

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NHEERL MS-97-019

PARTICULATE MATTER RESEARCH PROGRAM STRATEGY

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External Review Draft

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

October 1996

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1. INTRODUCTION

National Ambient Air Quality Standards (NAAQS) are established by the U.S. Environmental Protection Agency (EPA) to protect public health and welfare, based on scientific criteria. Currently, NAAQS exist for ozone, lead, carbon monoxide, nitrogen oxides, sulfur dioxide, and particulate matter (PM). Periodic reviews of the standards are required by law to ensure their adequacy.

Recent studies of several metropolitan areas in the United States and elsewhere report excess mortality and morbidity in urban populations associated with airborne PM concentrations below the current PM NAAQS. These studies suggest PM exposures may shorten the human life span of susceptible subpopulations (e.g., the elderly) and cause increased morbidity in these and other susceptible groups such as children. There are, however, several aspects of these epidemiologic observations that require further consideration; in particular, a clear biologic explanation for a cause-and-effect relationship has not yet emerged, and the nature of the concentration-response relationship across a wide range of concentrations and conditions is uncertain. These provocative epidemiologic findings underscore EPA's statutory mandate to review and potentially revise the NAAQS for PM. It is imperative to reduce key uncertainties to provide for the most effective and efficient health protection through the NAAQS.

The latest available scientific information on PM is evaluated in an ambient air quality criteria document (AQCD) (U.S. Environmental Protection Agency, 1996a) prepared by EPA's Office of Research and Development (ORD) and peer reviewed by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board (Wolff, 1996a). Key scientific findings from the AQCD have been drawn on and summarized in a Staff Paper for PM prepared by EPA's Office of Air Quality Planning and Standards (U.S. Environmental Protection Agency, 1996b), which also was peer reviewed by CASAC (Wolff, 1996b). The Staff Paper makes recommendations that will form the basis for upcoming EPA decisions regarding proposed actions on the PM NAAQS.

In the course of assessing the latest scientific information on PM, various data gaps and uncertainties have been identified, which, if addressed by research, could lead to improvements in the databases later available to support NAAQS review. To this end, EPA has developed a document entitled Particulate Matter Research Needs for Human Health Risk Assessment (U.S. Environmental Protection Agency, 1996c). The PM research needs document is designed

to serve as the basis for development of health research plans by EPA and other organizations. The intersection of the PM research needs document with the Strategic Plan for the Office of Research and Development (U.S. Environmental Protection Agency, 1996d) provides the context for the present document, which describes the research strategy for EPA's research on PM.

The EPA has a dual responsibility to review the adequacy of the NAAQS every 5 years and to ensure attainment of the NAAQS to protect public health and welfare. The EPA health effects and exposure research supports NAAQS review by providing scientific methods, models, and data needed for assessment of health risks from PM exposures. The EPA research to support implementation of PM standards is focused similarly on improving the methods, models, and data for attainment decisions. In this area, the research program is designed to ensure that federal, state, and local regulatory officials have the information and tools necessary to make objective and informed judgments about the viability of alternative attainment strategies. The direct linkage of risk management research to the risk assessment process provides the unique opportunity for EPA researchers to focus the national research agenda on the most critical uncertainties that could significantly impede future attainment of the PM standard.

This document describes ORD's PM research strategy in the areas of health, exposure, risk assessment, and risk management research and will be used to guide ORD's future PM research. It also will provide the scientific community and the public the opportunity to review and comment on the ORD PM research strategy.

The ORD approach to planning and implementing research on PM is multidisciplinary. The EPA staff from the ORD National Health and Environmental Effects Research Laboratory (NHEERL), the ORD National Exposure Research Laboratory (NERL), the ORD National Risk Management Research Laboratory (NRMRL), the ORD National Center for Environmental Assessment (NCEA), the ORD National Center for Environmental Research and Quality Assurance (NCERQA), the ORD Office of Research and Science Integration (ORSI), and the Office of Air and Radiation (OAR) have developed this strategy cognizant of the need for integrated planning across various disciplines. Implementation of the EPA research program is also coordinated by a multidisciplinary committee composed of staff from the laboratories and offices identified above. The primary clients for this PM research program include OAR, EPA's Regional Offices, and state and local air pollution control agencies. It also will be of interest to the public, congress, the international scientific community, industry, and environmental groups.

This introduction (Section 1) describes the environmental problem of concern (see above), the research program mission, and the research program goals and scope. Section 2, the research planning framework, includes an assessment of current knowledge and identification of key questions. Section 3, the strategy, includes formulation of the strategy, criteria for ranking research, and research priorities. Section 4 is the summary.

1.1 Program Mission

The mission of ORD's PM research program is to provide an improved scientific basis for future regulatory decisions concerning public health risks posed by airborne particles. The strategy has been designed to balance research to support the future Clean Air Act-mandated reviews of the NAAQS for PM with research aimed at supporting implementation of PM standards, including improved understanding of sources, exposures, atmospheric and biological processes, and risk management technologies.

1.2 Program Goals

The fundamental goals of the PM research program are (1) to address key scientific questions relating particulate matter sources, exposures, and human health effects; (2) to assess the health risks; and (3) to provide EPA and other stakeholders with technical information needed to understand the costs and performance of risk management options. Acquisition of this knowledge is needed to address policy questions related to the risks posed by PM.

It is important to plan how research will be utilized in risk assessment and regulatory activities because these considerations can influence the timing of research. A long-term research program is required to address critical PM issues fully and will be important for future PM NAAQS reviews. As an intermediate step in achieving the long-term goals, the program described here also will produce important information in the near term that can have dramatic impact on EPA's ongoing regulatory development strategy and its implementation (e.g., Federal Reference Method development).

1.3 Program Scope

The EPA's PM research strategy addresses several key issues to support NAAQS decisions and implementation. These issues are (1) the need for further interpretation of the epidemiologic data; (2) the limited understanding about biological mechanisms that could (a) explain the observed effects, (b) provide insight with respect to physico-chemical composition of the particles causing effects, and (c) explain the nature of the concentration-response function, in particular with respect to the possibility of a threshold for effects (i.e., every exposure concentration may cause an effect in some individuals in the population); (3) the uncertainties about the composition, size, physical properties, and sources of PM that may cause health effects; (4) the incomplete understanding of the aerosol transport and exposure processes (where, when, and how people are exposed to ambient PM); and (5) what existing and new risk management technologies can be cost-effectively used to control emissions of $PM_{2.5}$ and PM_{10} .

Air pollutants exist as a complex mixture, and exposure to this mixture of PM and copollutants has been associated with increased health risks. Although EPA's PM research program is focused on PM issues, it is complemented by other ongoing and planned EPA research programs focused on, for example, important copollutants such as ozone. In addition, research regarding any potential ecological effects of PM constituents, such as from acidic deposition, or regarding development of control options for well-known PM precursor source categories, such as utility boilers that emit sulfur and nitrogen oxides, are not addressed in this research strategy. If identified as a priority for EPA research, such associated effects, exposure and management research issues are addressed in ongoing and planned research activities and strategies that are complementary to this PM strategy.

2. RESEARCH PLANNING FRAMEWORK

Two steps were undertaken as part of the strategic process to develop this plan: (1) assessment of current knowledge and (2) identification of major knowledge gaps and key scientific questions. The results of these two steps are described in abbreviated fashion in this section. The AQCD and research needs documents discussed in the introduction were used as a resource in designing this strategy.

2.1 Assessment of Current Knowledge

Health Effects of Particulate Matter

Health effects reported to be associated with PM are summarized in the AQCD (see U.S. Environmental Protection Agency, 1996a; Table 12-2 and Tables 12-8 through 12-13). Effects can be grouped into two categories: (1) increased daily and annual mortality rates in adults, including those from cardiopulmonary disease, and (2) increased morbidity from cardiopulmonary disorders, including symptoms of respiratory dysfunction (e.g., wheeze, cough), asthma attacks, pneumonia, bronchitis, and chronic obstructive pulmonary disease. Other measures of morbidity, such as restricted activity due to illness, increased emergency room visits, and increased rates of hospitalization, also have been associated with ambient PM exposures. Table 1 summarizes reported effects.

Preexisting respiratory or cardiopulmonary disease and age appear to be important factors in PM susceptibility (U.S. Environmental Protection Agency, 1996a; Tables 13-6 and 13-7). According to recent epidemiologic studies, risks of PM-associated mortality appear to rise after age 40, particularly in individuals over 65 who have preexisting disease but who are not necessarily hospitalized. The average life shortening of affected individuals cannot be quantified with confidence but could conceivably be on the order of years (U.S. Environmental Protection Agency, 1996a).

Younger individuals also may be at increased risk relative to the general population. Increases in morbidity associated with increased PM exposures are reported in children in the United States, The Netherlands, and Austria. Acute pulmonary function studies are suggestive of a short term effect resulting from PM pollution, with effects larger in groups such as asthmatics (U.S. Environmental Protection Agency, 1996a; Table 12-13).

Animal toxicology studies have been conducted with various types of model particles (e.g., titanium dioxide, latex, iron oxide). In general, these studies suggest relatively low toxicity for these types of PM. Few studies have been conducted with ambient urban air particles (U.S. Environmental Protection Agency, 1995). Studies comparing the in vivo and in vitro toxicity of a range of particles demonstrated that particles collected from the ambient urban air are more toxic than a number of model particles (Hatch et al., 1985; Becker et al., 1996).

TABLE 1. SUMMARY OF REPORTED HEALTH EFFECTS ASSOCIATED WITH PARTICULATE MATTER EXPOSURES

Mortality
Total deaths
Respiratory deaths
Cardiovascular deaths
Cancer deaths
Increased Hospital Use
Admissions
Emergency room visits
Increased Pneumonia and Exacerbation of Chronic Obstructive Pulmonary Disease
Hospital admissions
Emergency room visits
Exacerbation of Asthma
Attacks
Bronchodilator use
Emergency room visits
Hospital admissions
Increased Respiratory symptoms
Cough
Upper respiratory tract
Lower respiratory tract
Decreased Lung Function
Forced expiratory flow
Peak flow

Modified from Dockery and Pope (1994), Schwartz (1994a,b,c).

More recent animal studies suggest that higher toxicity is associated with the use of animal models of cardiopulmonary disease, smaller size (higher collective surface area) particles, and particles with higher content of soluble metals or organic matter. A possible mechanism underlying mortality and morbidity may be the induction of oxidant production, lung inflammation, and hyperactivity by these surface-associated components of PM (Oberdörster et al., 1992; Costa et al., 1994; Cohen et al., 1996; Gutteridge et al., 1996; Pierce et al., 1996; Samet et al., 1996). It is also likely that differences in air flow in the diseased lung versus the

normal lung alter dosimetry and result in greater regional or localized PM deposition in diseased lungs. This is likely to contribute to the effects of PM (Kim et al., 1988; Bennett et al., 1996a,b).

In addition to cardiopulmonary effects, genotoxic and carcinogenic effects are of concern. Particulate matter collected from the ambient air contains condensed organic matter that is carcinogenic in animals and mutagenic in short-term bioassays (Lewtas, 1993; Cupitt et al., 1994).

Exposure to Particulate Matter

Figure 1 summarizes current knowledge of the mass distribution by size and categories of sources of PM. This figure shows that ambient PM is a complex mixture of sizes and types of particles that are emitted into, or formed in, the atmosphere with contributions from many sources. The size, chemical composition, and source of particles all may play a role in health effects resulting from PM exposures. This figure also indicates that particles generally are distributed bimodally by size in the atmosphere, with the minimum of the distribution between 1 and 3 μm aerodynamic particle diameter. Fine particles, including acid aerosols, appear generally to be distributed evenly across metropolitan areas, although city-center concentrations of acid aerosols tend to be lower due to ammonia neutralization (Burton et al., 1994; Suh and Burton, 1994). Little detailed information is available on the specific structure and chemical makeup of particles, especially the metal speciation and semivolatile organic components of fine particles. Even less is known about particle surface composition.

Few personal monitoring studies, where exposure is determined from monitors attached to individuals as they conduct their daily activities, have been conducted. Personal exposures to PM_{10}, while subjects are spending time indoors and outdoors are, however, invariably higher than simultaneously measured ambient and indoor PM_{10}. For example, Clayton et al. (1993) showed during the daytime, while people are active, that personal exposures to PM_{10} averaged 150 $\mu g/m^3$, whereas simultaneously both the indoor and outdoor PM_{10} averaged 95 $\mu g/m^3$. The enhancement of personal exposure relative to the PM_{10} concentrations within occupied indoor and outdoor microenvironments is believed to arise from personal activities that generate PM_{10} close to the subject but at a distance from the stationary indoor and outdoor PM_{10} monitors. This may possibly explain why human exposures to PM do not always correlate well with

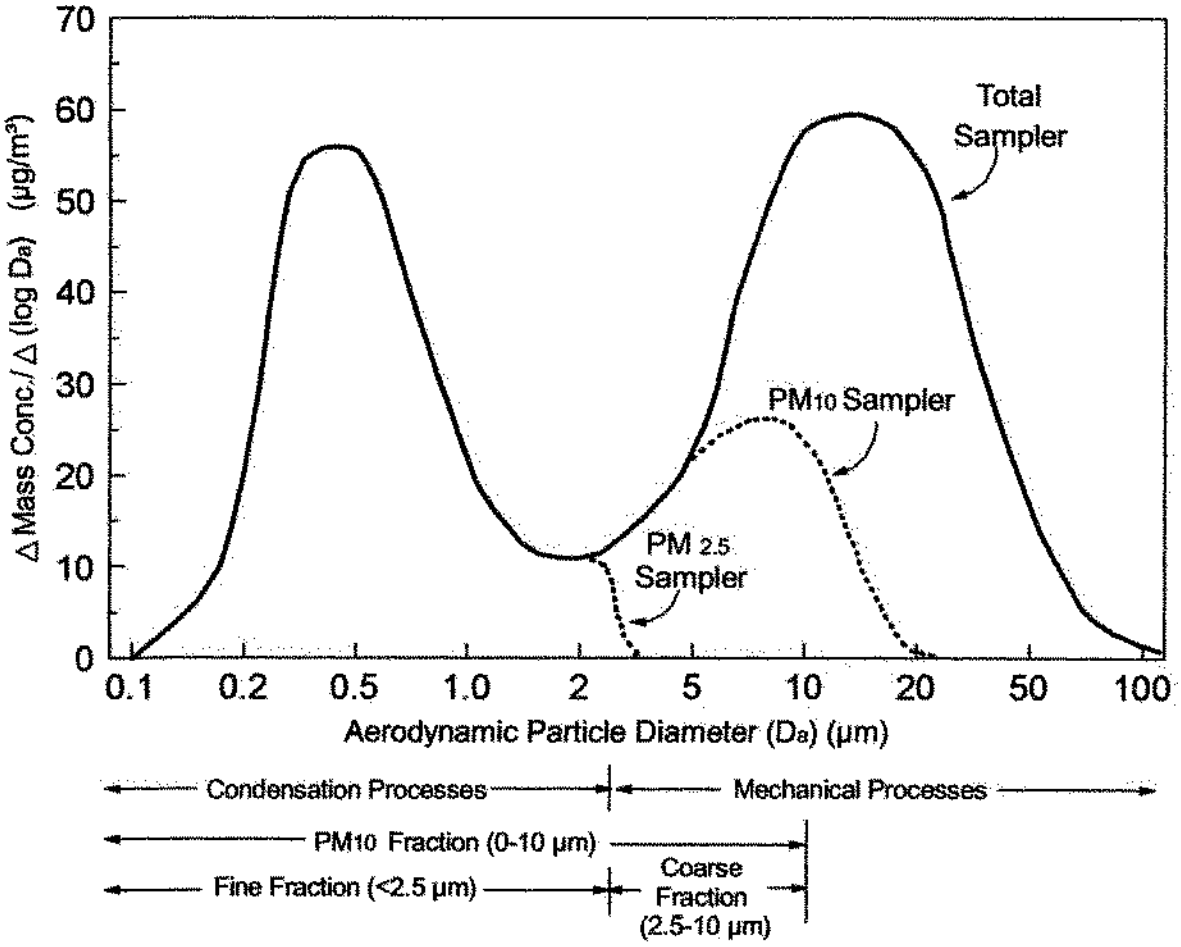

Figure 1. Sampling fractions related to a typical ambient particulate mass distribution. A typical bimodal distribution is shown. Particles in the finer mode include primary particles from high-temperature metallurgical and combustion processes, secondary particles from atmospheric reactions, and fine particles that have been deposited and resuspended by wind or human activities. Particles in the coarser mode include coarse windblown and road dust, pollens and spores, and some industrial particles.

ambient PM measurements. In homes with significant indoor sources of PM (e.g., cigarette smokers), outdoor measurements do not correlate well with indoor measurements. In studies that control for homes with significant indoor sources, indoor levels of fine particles are highly correlated with outdoor levels (Lewis, 1991). Because of the epidemiologic associations of mortality with ambient PM that have been reported (Schwartz et al., 1996), it is important to understand how community ambient PM concentrations and personal exposures to PM of ambient

origin relate, particularly in reference to time and activity patterns and to residential and other indoor microenvironmental concentrations of PM.

The most commonly used ambient air sampling devices collect particles on filters. Continuous monitors, which are based on direct measurement of mass, beta-ray attenuation, light scattering, particle mobility, or other physical properties of particles, also have been developed but are used infrequently. Characteristics and uses of various ambient, indoor, and personal sampler types are summarized in Table 2. Along with the rulemaking for a revised PM NAAQS, EPA has developed and is proposing a new Federal Reference Method based on these methods to be used in determining compliance with any new ambient standard. However, the new method will not supply sufficiently detailed information needed for full assessments of public health risks. Needed are integrated (averaged over a long sampling period) and real-time methods. Integrated PM measurement accuracy is limited substantially by factors that include performance variations in sampler inlets and size discriminators, internal losses, variations in particle composition and chemical changes, loss of volatile and semivolatile components, and variable moisture content.

The myriad of exposure possibilities makes actual measurement of all cases impossible, thereby producing a need for atmospheric and exposure models. Modeling is critical for a complete assessment of both personal and environmental exposures. More useful models help define the nature of PM exposures and include consideration of emissions characterization, aerosol chemistry and dynamics, and human exposure. Information that serves as input to these models and the models themselves currently are underdeveloped. In particular, research is needed in the areas of urban-to-regional scale model development, aerosol chemistry and dynamics, emissions characterization, indoor-outdoor relationships, and human exposure model development. Validation of newly developed models is essential if they are to be used to support advanced risk assessment and regulatory decisions.

Assessment of Risk from Particulate Matter

The current state of knowledge on the health risks of particulate matter is summarized in the AQCD for PM, which recently has been updated (U.S. Environmental Protection Agency,

TABLE 2. INTEGRATED AEROSOL SAMPLERS AND CONTINUOUS PARTICLE MONITORS

Integrated Aerosol Sampler	Operating Principle	Particle Size Range (µm)	Flow Rate (Lpm)	Use/Comments
TSP Hi-Volume	Sheltered filter	0-45	1,400	Ambient monitoring
PM_{10} Hi-Vol	Impactor/cyclone	0-10	1,130	Ambient monitoring
Dichotomous	Virtual impactor	0-2.5 2.5-10	16.7	Ambient monitoring, source apportionment
Dichotomous	Virtual impactor	0-2.5 2.5-10	1,130	Ambient monitoring, source apportionment
PEM/MEM[a]	Impactor	0-2.5 2.5-10	2-10	Indoor monitoring, personal exposure
MOUDI[b]	Impactor	0.05-10	30	Particle size, 10 stages
Berner	Impactor	0.063-16.7	30	Particle size, 9 stages

[a]PEM = personal exposure monitor; MEM = micro environmental monitor.
[b]MOUDI = micro orifice uniform deposit impactor.

Continuous Particle Monitor	Operating Principle	Particle Size Range (µm)	Flow Rate (Lpm)	Use/Comments
Beta-Gauge	Beta-ray attenuation	--	16.7	TSP, PM_{10} monitoring
TEOM[c]	Direct mass sensor	--	16.7	TSP, PM_{10}, $PM_{2.5}$ monitoring
Integrating Nephelometer	Light scattering	0-3	75	Visibility monitoring
OPC[d]	Light scattering	0.3-10	Variable	Particle size, number
APS[e]	Time of flight	0.5-10	5	Particle size, number
DMPS[f]	Electrical mobility	0.003-1	4	Particle size, number

[c]TEOM = tapered element oscillating microbalance.
[d]OPC = optical particle counter.
[e]APS = aerodynamic particle sizer.
[f]DMPS = differential mobility particle sizer.
-- = not applicable.

1996a). Additional assessment methods should be developed to facilitate the future AQCD; these include the following: (1) analyses of lung function as a predictor of mortality and time of life lost; (2) determining effects of altitude on the risk of health effects from particles; (3) developing statistical models for identification of air pollution episodes and estimation of short-term temporal displacement of mortality and morbidity; (4) developing statistical models for evaluating interactions of PM, copollutants, and weather in regression models for mortality and morbidity; and (5) understanding the relative effects of $PM_{2.5}$ versus coarse particles on asthmatics as a sensitive population.

Management of Risk from Particulate Matter

Managing the health risks of exposures to particles requires knowledge of the sources and types of particles that are most likely to cause health risks and knowledge of the performance and costs of risk reduction technologies. Both direct emissions of PM and secondary particle formation caused by the oxidation of SO_2, NO_2, and aerosol organic carbon species contribute to overall levels of airborne particles. The major constituents of coarse particles across the United States are minerals, and the major constituents of fine particles vary by region, with sulfates as the major component in the eastern United States and elemental and organic carbon species dominant in the western United States (see Figures 2 and 3; U.S. Environmental Protection Agency, 1996a). The most recent data on the PM effects described in the AQCD indicate that the association between fine particles and adverse health effects tends to be stronger than the association with coarse particles. Such a finding has implications for risk management activities which must begin to consider how PM attainment strategies would have to be modified to reduce atmospheric levels of fine particles. For example, in the eastern United States, additional reductions of sulfur oxides associated with fossil fuel combustion and motor vehicle emissions may be necessary, whereas, in the West, additional reductions of inorganic and elemental carbon species emitted from wood-burning activities and mobile sources could be required.

The availability of tools to assess attainment strategies and approaches to manage PM risks varies widely depending on the size fraction and constituent of concern. Available atmospheric models and emission estimation techniques used by states to devise attainment strategies were

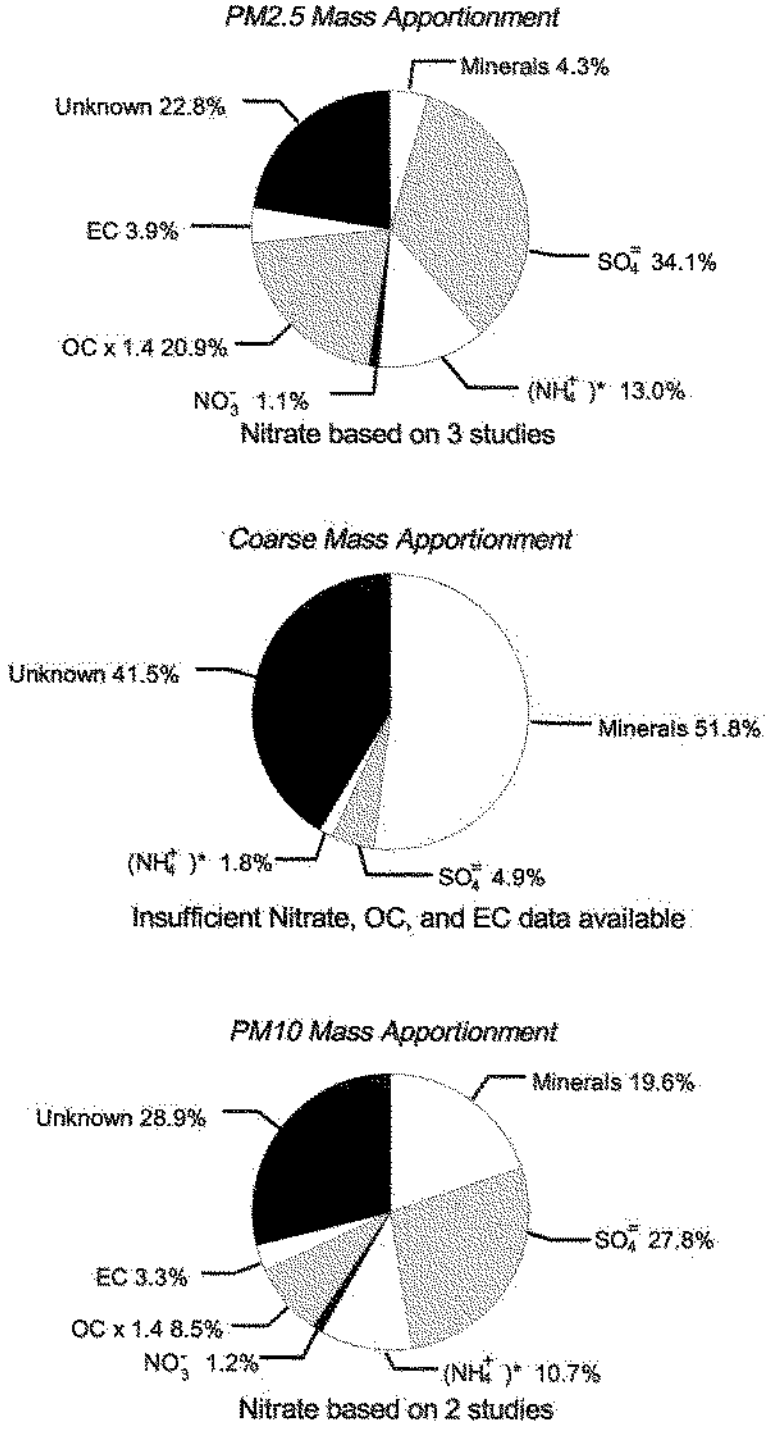

Figure 2. Major constituents of particles measured at sites in the eastern United States. $(NH_4^+)^*$ represents the concentration of NH_4^+ that would be required if all $SO_4^{=}$ were present as $(NH_4)_2SO_4$ and all NO_3^- as NH_4NO_3. Therefore, $(NH_4^+)^*$ represents an upper limit to the true concentration of NH_4^+.

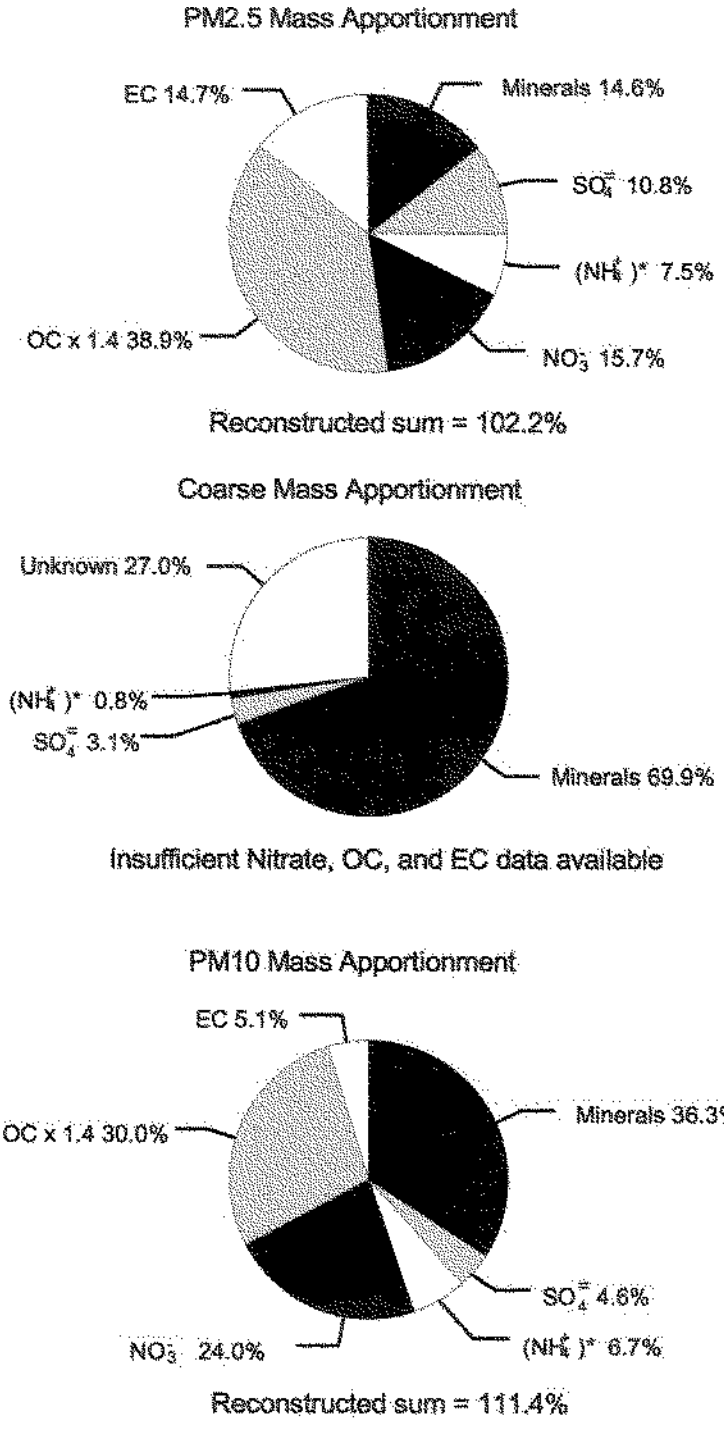

Figure 3. Major constituents of particles measured at sites in the western United States. $(NH_4^+)^*$ represents the concentration of NH_4^+ that would be required if all $SO_4^=$ were present as $(NH_4)_2SO_4$ and all NO_3^- as NH_4NO_3. Therefore, $(NH_4^+)^*$ represents an upper limit to the true concentration of NH_4^+.

designed to support implementation of the existing PM_{10} standards and have not been refined to address smaller size fractions or adequately taken into account all the atmospheric transformation processes that lead to secondary particle formation. Although much is known about emission levels of the precursors that lead to secondary particle formation, most of the estimates of primary $PM_{2.5}$ emissions are derived from data on PM_{10}, resulting in some uncertainties in the fine particle emissions inventory. This is especially true for fugitive sources. In addition, there is a general lack of data on the chemical composition of fine particle emissions. The need for emission characterization is greatest for those sources with constituents (such as metals, acidic components) that are candidates for causal mechanism studies of respiratory health effects. The availability of approaches to control both primary and secondary particles also varies widely with existing technologies available to reduce SO_x and NO_x from most large fossil fuel combustion sources and improvements or upgrades needed to limit emissions of primary particles from some source categories, particularly in cases where space limitations make existing approaches infeasible. Appendix 1 provides details on the current state of knowledge concerning management of fine particle emissions.

Appendix 1 includes data on the effectiveness and costs of emissions prevention, emissions reduction, or exposure reduction technologies to reduce fine particle levels indoors and outdoors. Approaches to reduce indoor fine-particle exposures are not well understood, with only limited data available on the efficiency and cost of air cleaning to remove particles from indoor air and virtually no data on the effectiveness of air cleaning in reducing exposures to fine particles. Because indoor concentrations of particles are generally about the same as outdoor concentrations when outdoor concentrations are high, or about twice outdoor concentrations when outdoor concentrations are low (e.g., Spengler et al., 1981; Sheldon et al., 1989), and because people spend roughly an order of magnitude more time indoors than outdoors, the effectiveness of indoor exposure controls is also a major uncertainty.

2.2 Identification of Key Questions

The thrust of this research plan is to address key scientific and technological questions regarding those aspects of airborne PM that may affect human health adversely. The key questions are drawn mostly from the PM research needs document (U.S. Environmental

Protection Agency, 1996c) and, ordered consistently with the health risk assessment paradigm, are listed below.

A. What are the causal, biologic mechanisms of effects and the implications for (1) initiation and progression of pulmonary injury, inflammation, hyperreactivity; (2) exposure-dose-responses; and (3) impacts on subpopulations? What are the mechanisms and rates of repair for the tissues and cells of the different respiratory tract regions across age, sex, and health status in humans and across species? Do host factors such as age, sex, and health status influence the number or types of target cells and their relationship to toxicity/detoxication of PM? Can laboratory animal models be developed that are homologous to the human population at risk in terms of host factors and mechanisms of action?

B. What is the spectrum of acute and chronic health effects of particulate matter? Does ambient PM exposure lead to
   1. Exacerbation or initiation of pulmonary injury, inflammation, hyperreactivity;
   2. Extrapulmonary effects, such as cardiovascular system effects; or
   3. Cancer of the lung or other organs?

C. Can ambient PM impacts on population morbidity and mortality be better characterized in relation to potential effects modifiers and confounders such as meteorology and exposure to other pollutants? Can epidemiological and biostatistical methods further differentiate the effects of individual PM components? Similarly, can these methods help differentiate specific sources of PM from the entire ambient PM complex or the entire air pollution complex (including gases and particles)?

D. Who is being affected by ambient PM exposures, and what are important factors putting them at risk? What sensitive subpopulations are most affected by PM exposures? Are there differences with regard to sensitive groups at risk because of acute versus chronic exposure effects? Can critical host risk factors be delineated, for example, with regard to
   1. Health status (preexisting cardiopulmonary disease, acute respiratory infection, COPD, asthma, etc.),

2. Age (children and the elderly),
3. Genetic factors (predisposition to emphysema, deficient lung defense mechanisms, cancer, etc.),
4. Life style (smoking, nutrition, access to health care, activity patterns/levels, etc.),
5. Differential respiratory tract dosimetry (regional deposition, and retention) as influenced by one or more of the above other factors, or
6. Prior occupational or other nonambient PM exposures (hobbies, indoor cooking/cleaning, etc.)?

E. How can dosimetry models be improved to contribute to evaluation of responses in epidemiological, controlled human exposure studies, and laboratory animal studies and to improve insight on potential mechanisms of action? What data are needed to enhance the ability of dosimetry models to describe the various factors, including both the physicochemical attributes of ambient PM, as well as host factors that influence inhaled dose, clearance, retention, and response? What data are required to construct the different internal dose metrics that may correspond to various plausible mechanisms of action? Can the variability in different dose metrics, both within humans and across species, be better characterized?

F. What are the shapes of the acute and chronic exposure-dose-response curves for ambient PM?

G. Are the apparent ambient PM effects on morbidity and mortality determined by
1. Physical properties of ambient particles (particle diameter, particle number, particle mass, and particle surface area);
2. The inorganic content of ambient particles, especially the presence of transition metals;
3. The organic content of ambient particles, especially the polar fraction;
4. The concentration in ambient particles of biologically derived material such as endotoxins;
5. The acidity of the ambient aerosol;
6. Other components of the atmosphere for which PM is a surrogate; or

7. Personal exposures, particularly indoor exposures, including the exposure patterns of susceptible populations and the so-called "personal cloud"?

H. What are the characteristics of ambient particulate matter in terms of
   1. Chemical composition,
   2. Size distribution,
   3. Variability (spatial variation across a given city on a day-to-day basis and from city to city on a longer term, regional basis; temporal variability over diurnal cycles), and
   4. Characterization of poorly understood specific PM components that depend on improved methods being developed and deployed (e.g., "live aerosol" versus "dead particles", insoluble core, material soluble in aqueous layer, and outer skin); primary biological components (fragments of insects, molds, and plants); bacteria, viruses, etc.; semivolatile organic compounds; and ammonium nitrate?

I. What portions of the population are exposed to effect-causing PM, and, based on monitoring and modeling projections, in what ambient environments and indoor microenvironments are they exposed?

J. How can standardized, widespread research-grade ambient PM monitoring best be achieved to provide improved air quality data for PM exposure (e.g., by
   1. Augmentation of existing local compliance monitoring networks in selected cities,
   2. De novo establishment of a research-grade national ambient monitoring network, or
   3. Use of expanded measurements of specific physical and chemical parameters and appropriate sampling frequency to better reflect continuous, daily, and seasonal variations in PM)?

K. What are exposure estimates for unmonitored areas, and what is the linkage of health effects to sources, based on improved models that
   1. Relate source emissions to ambient concentrations;
   2. Relate central site, indoor, and personal exposures;
   3. Link air quality and exposure models; or

4. Describe evolution of aerosol size distributions?

L. What are the sources of ambient and indoor particles to which the general population and susceptible subpopulations are exposed, and what are the relative contributions from mobile, stationary, and fugitive sources, including gasoline and diesel fueled vehicles, stationary combustion, paved roads, construction sites, residential wood combustion, and animal wastes?

M. What are the costs and effectiveness of technologies to prevent and control exposures to (and ultimately, risks from) fine particles, and what low-cost approaches are available to ensure that emission reductions are achieved and verify that technologies are performing as designed?

3. STRATEGY

In the formulation of this strategy, critical gaps in scientific knowledge and the resulting scientific questions (identified above) were considered in the context of their impact on EPA's regulatory efforts and relative to corresponding research being conducted by other federal agencies and the private sector. The EPA's regulatory needs include an improved scientific basis for NAAQS determinations and improved scientific and technical information for standards implementation. To address EPA's regulatory needs, two approaches are necessary. One approach supports fundamental science that ultimately, but not immediately, will impact regulatory decisions, whereas the other provides methods and data that will support directly the assessment/regulatory effort in the near future. Both the short- and long-term needs of EPA were considered in setting the objectives of the program.

Next, criteria for setting priorities for EPA's PM research program were developed. Research efforts needed to address the key scientific questions then were ranked. Identification of priorities facilitates orderly development of a complex, integrated research program and focuses available resources. The pace at which research progresses will depend on the complexity of the scientific question and on available resources.

3.1 Criteria for Ranking Research

The criteria for ranking research within the PM program are listed below.

Risk-Based Planning. The focus is on research that reduces the greatest uncertainties in the assessment of health risk from exposure to airborne PM, and the cost-effectiveness of technologies for reducing emissions; exposures; and, ultimately, risks.

Scientific Excellence. The quality of the science is critical to development and testing of hypotheses, data collection and evaluation, and, ultimately, support of credible regulatory standards by EPA.

Policy Relevance. Importance is placed on the expected utility of the research products for addressing both short- and long-term regulatory issues.

Other Sources of Data/Information. The research currently being conducted by other organizations will be considered in setting priorities and allocating resources. Through venues such as the EPA PM Research Needs Workshop (held in September 1996) and the Committee on Environment and Natural Resources, which coordinates federal research activities, EPA is fully aware of research activities by other organizations, such as the Health Effects Institute and the Electric Power Research Institute, and among federal research organizations. This allows for more efficient allocation and leveraging of resources at EPA.

Capabilities and Capacities. This criterion focuses on research implementation issues; that is, ensuring that EPA has the facilities and expertise to conduct or oversee the needed research. In-house expertise is necessary to oversee research, even if it is conducted by cooperative agreement or contract. Capabilities of the extramural scientific community are tapped through EPA's investigator-initiated, competitive, peer-reviewed Request for Applications-driven Science to Achieve Results (STAR) grants program.

Sequence of Research. The conduct of some research, no matter how important, is dependent on the execution of previous studies. Research that depends on studies that have not yet begun or

are only partially complete will at this time receive lower priority, independent of its overall importance.

3.2 Research Priorities

When the ranking criteria were applied to the potential research efforts, research priorities emerged. Only the most important of the resulting research priorities are noted; current or future research in each of these areas is anticipated by EPA and collaborators or via the EPA's STAR program. Sequencing of research (i.e., the order in which research must be conducted) was an important factor in the ranking, as was the recognition that some research is needed in the near term to support standards implementation, whereas other research is needed in the longer term to support future NAAQS reviews. The priorities are discussed below (but not necessarily in priority order within the "Highest Priority" and "High Priority" groupings).

HIGHEST PRIORITY

Investigate Causal Mechanisms and Particle Characteristics. Identification of causal mechanisms is crucial because it could (1) provide a basis for understanding the associations observed in epidemiologic studies between adverse health outcomes and PM exposures; (2) clarify which particle types, sizes, and chemical and biological characteristics are associated with the effects; (3) provide information on source-exposure-response relationships, including the low-exposure range; and (4) help identify and characterize susceptible subpopulations.

There are a number of hypotheses concerning potential causative agents and related mechanisms and little information to identify the correct hypothesis. Two hypotheses are currently the focus of NHEERL's efforts to understand particle-associated causative agents: (1) transition metals and (2) potentially toxic components of organic matter, including allergenic proteinaceous material and endotoxins. Animal models of human disease will be used to understand the mechanisms underlying PM effects. Additionally, in vitro evaluation of potential mechanisms and evaluation of dosimetry in animals and humans will be used in testing key hypotheses. Clinical studies also will play an important role as appropriate, safe protocols for human studies are developed.

Another hypothesis being investigated is that polycyclic organic components of urban air PM are rapidly released from the particles and either react with deoxyribonucleic acid (DNA) at the site of deposition in the lung or after transport to other target sites where toxicity is induced via genotoxic mechanisms. This research will focus on the development and application of biomarkers in human studies to better characterize the dose-response relationships between PM exposure and DNA dose in the cardiopulmonary system, blood, and excretion of metabolites in urine. Research is also in progress to investigate whether those electrophilic components of PM that may induce cancer or other effects also could be the most toxic components in inducing acute responses in vitro and in vivo in animals and humans.

Additional hypotheses are being identified and evaluated through the investigator-initiated grants (STAR) program, to ensure a broad-based scientific effort is targeted to address this important research need.

This research directly addresses Key Question A (biologic mechanisms) and provides a basis for addressing Key Questions B (acute effects), D (susceptibility factors), and G (particle composition). This research will be coordinated with and benefit from dosimetry research described below (Question E) and will provide a basis for addressing Key Question F (shape of the dose response).

Develop and Evaluate Particle Measurement Methods. The development and evaluation of methods to identify and measure atmospheric particles by size and type are critical to understanding the relationship of particles and human health effects and to the development and implementation of PM NAAQS. Research will focus initially on developments to improve methods supporting the emerging NAAQS requirements. An ongoing methodology research and development improvement program will be maintained to address uncertainties in existing PM methods and to develop new, cost effective approaches for emerging needs such as automated techniques to support every-day, hourly determinations of PM mass, methodology supplying chemical speciation, and application of real-time, portable counting and classifying techniques for particle size distribution.

This research addresses Key Questions G (particle composition), H (particle characteristics), I (human exposure), and J (ambient monitoring).

Characterize Ambient Particle Exposures. Identification of fine particles to which people experiencing adverse health effects are exposed is important to researchers trying to establish a biological mechanism leading to those effects. With these particles characterized, effects researchers will be better able to focus their investigative research; the converse is also true. If the responsible particle characteristics causing adverse effects and the corresponding biological mechanism were known, exposure researchers would know what data to collect. The current absence of either of these crucial pieces of information points to the need to work on both simultaneously until the answer to each is found. Mechanistic research needs are discussed above. New field measurements will be undertaken, using newly developed and evaluated methods to size and speciate particle composition over the range of concentrations and conditions typical of ambient air in different regions of the country. Profiles will be developed for regions dominated by secondary sulfate- and nitrate-based particulate formation, wood smoke, semivolatile organics, crustal materials, and fugitive dust. Hourly to diurnal temporal scales and local to regional spatial scales will be part of these profiles, as will a determination of the effects that meteorology has on the spatial and temporal distribution of ambient particle concentrations. This research and the information it provides will be designed expressly to serve the epidemiological and atmospheric modeling communities attempting to draw direct correlations between atmospheric concentrations and observed adverse effects in portions of the country's populace. This information will be supplied in the near term through intensive field campaigns and potentially supplied over the long term through a nationwide particulate monitoring network now being considered by OAR.

This research addresses Key Questions A (biologic mechanisms), G (particle composition), H (particle characteristics), I (human exposures), J (ambient monitoring), and K (exposure modeling).

Develop Atmospheric Models Supporting Regulatory Implementation

To support regulatory implementation, states need atmospheric modeling tools relating changes in source emissions to changes in ambient PM levels. Currently available models require substantial additional development and evaluation before they will be sufficiently useful in planning to achieve any new PM NAAQS. Research will develop and evaluate diagnostically emissions-based, regional-to-urban scale models that focus on interactions of urban and point-source plumes with the surrounding regional atmosphere in the transport and fate of fine particles,

using the EPA Models-3 framework. These models will be capable of addressing atmospheric loading of PM of varying size distributions and chemistry (toxicity and acidity) across varying spatial and temporal scales. Included is research that describes the interaction of boundary layer turbulence, vertical mixing, and cloud processes with atmospheric chemistry.

This research addresses Key Questions I (human exposure) and K (exposure modeling).

Characterize Source Emissions. Uncertainties in the quality of data in the current particle emissions inventory support the need for research to further clarify which sources are significant contributors of ambient fine particles (e.g., inventories for precursors that lead to secondary particle formation, except ammonia, are much stronger than those for sources of primary particles). In a recent emissions inventory (Knopes, 1994), the dominant sources of primary fine particle emissions were fugitive dusts from a variety of paved and unpaved roads, agricultural operations, and geologic sources. However, the aerodynamic impactors that were used to determine particle sizes from these sources are thought to have experienced "particle bounce", which may have skewed the data to show a higher fraction of fine particles than actually exists. Recent field studies to test this hypothesis compared these impactors to standard ambient $PM_{10/2.5}$ samplers. Results showed wide variability, even among the ambient samplers. A short-term, high-priority need is to determine the reliability of existing data that was collected with impactors. Once the cause and extent of the variability seen in the recent tests are determined, the validity of existing data can be assessed, and corrective measurements made as needed.

Additional measurements also are needed to fill data gaps in the inventory for potentially significant sources such as on-road, heavy-duty, diesel-powered vehicles, fugitive emissions from construction sites, road surface silt loadings, ammonia from animal wastes, transition metals from point and area sources, and construction activities. Work also needs to be done to quantify emissions from homes with current-generation wood stoves. The current database suggests that substantial increases in emissions can occur after only a few years use, but more data are needed to develop specific guidance for wood stove users and state implementation planners.

In addition, research is needed to characterize sources on the basis of potential toxicity. By associating toxic PM with a source type, research to produce effective mitigation strategies can be prioritized. Combustion emissions from a variety of stationary and mobile sources will be of primary interest. For example, particles generated by the combustion of No. 5 and No. 6 fuel

oils in NRMRL's combustion laboratory will be used in animal studies by NHEERL to evaluate mechanisms for tissue damage caused by short-term exposures to the particles. The particles also will be characterized for size distribution and composition, particularly with respect to metals.

This research directly addresses Key Question L (source emissions) and supports Key Question A (biological mechanism) by providing fly ash samples for toxicological testing. This work also will be closely coordinated with the programs described above to characterize ambient fine particle exposures (Question H) and to develop regional and urban-scale PM models (Question K).

HIGH PRIORITY

Evaluate and Test Epidemiologic Observations. Epidemiologic observations are the current source for concern regarding effects associated with PM. New analytical efforts have been initiated to reevaluate several of the major published epidemiological studies. Multidisciplinary field studies will include more intensive daily PM measurements of exposure and better characterization of PM and of individual human and population exposures and more extensive characterization of potential effects. Biomarkers of exposure to PM, personal exposure monitoring, and other approaches to improving human exposure assessment in selected subsets of the population will be considered in the design of future studies. Other measurements of morbidity, cellular inflammation, and early markers of adverse human effects from PM will be incorporated in study designs. Efforts to initiate and coordinate new epidemiologic studies, funded by federal, state, and other institutions, are underway. Specific hypotheses will be developed and tested through these efforts.

This research directly addresses Key Question C (epidemiology) and will provide further information on acute effects of PM exposures (Question B), identification of factors affecting susceptibility (Question D) and constituents of particles associated with toxicity (Question G).

Elaborate on Dosimetry. Particle deposition in humans may be a critical factor in susceptibility and varies significantly in different segments of the population. Little is known about dosimetry in children and individuals with preexisting disease or about particle deposition of realistic urban

aerosols. Research will be conducted to determine (1) the dose delivered to sensitive subpopulations (e.g., asthmatics, chronic obstructive pulmonary disease patients) and (2) the distribution and retention of PM as a function of particle size. Refining dosimetric models may be critical to explaining the impact of particles on sensitive subpopulations. Also, these models will be important in extrapolation from animals to humans and across exposure scenarios. As animal and human clinical studies progress, the initially developed theoretical models can be validated and improved.

This research directly addresses Key Question E (dosimetry) and will provide information useful for understanding potential mechanisms of toxicity (Question A), identifying factors affecting susceptibility (Question D), and determining constituents of particles associated with toxicity (Question G). Improved understanding of dosimetry also will reduce uncertainty in characterizing the exposure-dose-response relationships (Question F).

Improve Understanding of Exposure-Dose-Response Relationships. To determine the appropriate level (concentration) and form (exposure duration and frequency) of the PM standard, laboratory and clinical studies will be conducted to understand exposure-dose-response relationships. Research to characterize the shape of the dose-response relationship, at low concentrations in particular, will be conducted to more confidently develop and apply threshold or nonthreshold models. Exposure duration and frequency issues will be explored in detail. The current lack of understanding limits the ability to study at-risk human subjects in a clinical setting. Consequently, evaluation of the responses of laboratory animals and then low-risk, normal populations to ambient and "inert" test particle exposures, with and without exercise, must be the first steps in the analyses of PM-related effects. Various endpoints, such as pulmonary function, particle clearance, inflammation, and airway reactivity, will be assessed. These studies can provide insight into population responses and allow further development of techniques to evaluate effects. These studies also could form the foundation for exploration of exposure-response issues in at-risk susceptible subpopulations.

This research directly addresses Key Question F (exposure-dose-response realtionships) and will provide further information on acute effects of PM exposures (Question B), identification of factors affecting susceptibility (Question D), and determination of constituents of particles associated with toxicity (Question G).

Improve Personal Exposure Assessment. Several research studies will be undertaken to improve personal exposure information: (1) measurement of personal exposures to airborne particles of nonhospitalized elderly persons, particularly those with respiratory or cardiopulmonary disease; (2) determination of the relationship between personal and microenvironmental exposures for these and other susceptible individuals; (3) determination of the relationships between the outside ambient environment and indoor microenvironments for airborne particle exchange and between indoor environments and a person's immediate microenvironment (the "personal cloud"); (4) measurement and definition of the characteristics of the personal cloud, and (5) determination of the utility of ambient air measurements to predict human exposures to particles of ambient origin.

This research addresses Key Questions G (particle composition) and I (human exposure).

Refine and Develop New Human Exposure Modeling. To get a reasonable estimate of individuals' exposure to particles, it is necessary to employ exposure modeling techniques to fill in data gaps where measurements do not exist or are not affordable. Further development of particle exposure models and thorough validation of these models are needed. A model is needed for evaluation of policy decisions linking effects to exposures and alternative air quality standards for particles. Important research studies in human exposure model development that are needed include (1) developing improved methods (e.g., dispersion modeling, mass balance modeling) for elucidating the relationship between indoor air quality and the composition of outdoor air, including microenvironments contributing to health effects from particles; (2) modeling short-term exposures (i.e., peak exposures) and gradients for dispersion, deposition, and ventilation in indoor microenvironments; and (3) integrating current activity pattern data with exposure model development and collection of additional information on activity (including data on physiological parameters such as respiration rates) as it relates to personal exposure to particles.

This research addresses Key Question I (human exposure).

Conduct Scientific Assessments. Periodic scientific assessments that draw together effects and exposure research results are required by the Clean Air Act. They will be performed by NCEA by critically evaluating published research results from ORD laboratories and other (federal, academic, and industry) research groups on the health and environmental effects of PM. These assessments will be used in preparing revised air quality criteria for particulate matter to support NAAQS decision making and as inputs to Clean Air Act cost-benefit analyses.

Develop Tools To Support New Market-Based Regulatory Approaches. The EPA is transforming its regulatory approach from command and control to a more flexible market-based system that provides regulated industries with the opportunity to achieve required air emission reductions in the most cost-effective manner. Air pollutant trading programs will be more widely used and will likely include PM. In order to have confidence that the market-based approach is achieving the needed emission reductions, low-cost techniques are required to determine if the source controls implemented are adequate. One of the problems that could impede successful implementation of this new approach is the current way facilities test and report emissions. The practice of reporting emissions only during carefully controlled operating periods has been estimated to underreport PM emissions for some categories by a factor of two or three (McIlvaine, 1994). Currently available continuous PM monitors require extensive calibration to the specific source and are usually affordable only to larger sources. A universal system of emission estimating, (i.e., parametric or predictive emission monitoring) may be developed through integration of state-of-the-art mathematical models for current control technologies and process control hardware. This effort will provide the operator precise process controls and diagnostic tools, while also producing continuous operations data that may be accurately correlated to mass emissions data.

This research directly addresses Key Question M (ensure emission reductions are achieved).

Improve Particulate Matter Control Technology. Significant reductions in emissions from existing sources may be required to reduce exposure to ambient PM to meet future NAAQS. Efforts to reduce PM levels, particularly those of fine particles, will require reductions from a combination of source categories that emit both primary particles and precursors that lead to secondary particle formation. Technologies are available for many sources; however, in some cases, there are questions about the feasibility of applying these existing controls to particular source categories, particularly those comprised primarily of smaller sources. One approach to reduce emissions from these difficult to control sources is to improve the operation and maintenance of available particle control technology. Given the long lead times involved, research in the near term is needed to determine the level of emission reductions that can be cost-effectively achieved through improved operation and maintenance practices. The most promising approaches can be evaluated at pilot scale and demonstrated at full scale in cooperation

with an industry partner. In situations where improved operation and maintenance do not provide sufficient emission reduction, proper application and optimization of existing retrofit technology should be considered. Such technology can be evaluated at small pilot scale. Examples of retrofit technology that readily can be piloted and offered to users include improved charging of electrostatic precipitators (ESPs; prechargers) and electrostatically augmented fabric filtration. The former technology improves the ESPs ability to handle various dust characteristics, whereas the latter enables bag houses to operate at considerably lower bag pressures, reducing leaks and wear. If existing retrofit technology cannot be modified, adequately hybrid technologies such as wet scrubbers-ESPs also will be investigated to determine their capability for more efficient cost-effective PM control. The results of such evaluations can be used by regulatory officials to compare the effectiveness of technologies for fine PM control and by the private sector to design and operate full-scale systems with confidence. In addition, ORD will prepare a guidance document for small sources of PM that do not use adequate PM control technology because the owners or managers of the source do not have adequate knowledge of the options available. The guidance document will provide cost and performance information needed to select, operate, and maintain PM control systems.

This research directly addresses Key Question M (cost and effectiveness of PM technologies).

4. SUMMARY

This document describes the process used to develop EPA's PM research strategy and presents a PM research program for addressing health, exposure, risk assessment, and risk management issues. The strategy is focused on the resolution of issues resulting from the new epidemiology observations suggesting serious health effects due to PM. The primary mission of this research program is to improve the scientific and technological basis for decisions concerning public health risks posed by PM. In particular, key issues are (1) further interpretation of epidemiologic findings; (2) the limited understanding of biological mechanisms that could explain the observed effects, provide insight with respect to physico-chemical composition of the particles causing effects, and explain the nature of the concentration-response function, in particular with respect to the possibility of a lack of a threshold for effects; (3) uncertainty about the

composition, size, physical properties, sources, and controllability of PM that may cause health effects; and (4) the incomplete understanding of the aerosol transport and exposure process.

Table 3 summarizes and links the key scientific questions and research priorities for the period FY97 through FY99. The mechanisms by which the research will be done, including via EPA intramural principal investigators and the extramural STAR program, will be determined as the program is implemented and with due consideration of the capabilities and capacity of EPA and others to conduct the needed research.

TABLE 3. PARTICULATE MATTER RESEARCH STRATEGY SUMMARY

Risk Paradigm	Science Questions	FY97	FY98	FY99
Effects	What are the biological mechanisms of effect? Can improved methods address confounding and improve interpretation of epidemiologic observations? What affects the dosimetry of PM? What are the shapes of the exposure-dose-response curves?	Investigate causal mechanisms and particle characteristics → Evaluate and test epidemiology observations → Elaborate on dosimetry → Improve understanding of exposure-dose-response relationships →		
Exposure	What types and concentrations of particles are people exposed to? Where are they exposed?	Develop and evaluate particle measurement methods → Develop atmospheric models → Characterize ambient PM exposures → Improve personal exposure assessment→		
Risk Assessment	What is the state of knowledge of PM exposure and effects?			Conduct scientific assessments →
Risk Reduction	What sources of particles need the most control to reduce risk? What are the most cost-effective approaches to reducing fine particle exposure and risk?	Characterize source emissions → Improve PM control technology→	Tools to support new market-based regulatory approaches →	

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APPENDIX 1: Overview of Current Knowledge of Risk Management of Fine Particles

[Numbers in regular type are typical values, selected from the referenced literature; entries in italics are estimates or judgments by ORD staff.]

Source Type [References]	Constituents of Concern	Total U.S. Emission Rate (10^3 tons/year) $PM_{2.5}$	PM_{10}	Approximate U.S. Population in Close Proximity	Primary Control Options, Efficiencies for PM_{10}	Approximate Costs of Current Particle Controls
Roads [1,2,3]	Fine silica and other crustal elements plus industrial reentrainment of carbon, asbestos, and metal compounds	3,300[a]	18,000	*Essentially the entire population*	*Vacuum sweeping (0-50%)* *Water flushing and sweeping (0-96%)* *Paving and roadside improvements* *Covering trucks* *Speed and traffic reduction*	*Dependent on type of control, time of event, frequency of events/year, and volume of traffic; very limited published data*
Agricultural Production (including erosion) [1,2,3]	Fine silica and other crustal elements	2,000[a]	11,100	*Mostly in rural areas*	*Low tillage, punch planting, crop strips, vegetative cover, windbreaks* *Chemical stabilizers, irrigation*	*Dependent on crop type and regional weather conditions; little data*
Construction Activities [1,2,3]	Fine silica and other crustal elements, plus industrial reentrainment of carbon, asbestos, and metal compounds	1,700[a]	8,500	*Mostly in urban areas*	*Wet suppression of unpaved areas, material storage, handling and transfer operations* *Wind fences for windblown dust*	*Dependent on type of control, time of event, land area of event, and activity level of equipment; very limited published data*
Open Burning (including wildfires, agricultural burning, etc.) [1,2,3]	Products of uncontrolled combustion	1,130[a]	1,320	*Mostly in rural areas*	*Low wind speed and appropriate wind direction*	*Unknown*
Residential Wood Combustion [1,2,3]	POM	550	≈550	*Mostly in urban areas*	*Replace with cleaner burning stoves*	*≈$500 per replaced stove*

APPENDIX 1 (con't). Overview of Current Knowledge of Risk Management of Fine Particles
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Source Type [References]	Constituents of Concern	Total U.S. Emission Rate (10^3 tons/year) $PM_{2.5}$	PM_{10}	Approximate U.S. Population in Close Proximity	Primary Control Options, Efficiencies for PM_{10}	Approximate Costs of Current Particle Controls
Diesel Engine Combustion [1,2,3]	Products of incomplete combustion, PM precursors (No_x)	450	500	*Mostly in urban areas*	*Combustion modification* *Improved fuel characteristics* *Particle traps*	*Very limited published data*
Mineral Products Production [1,2,3]	Fine silica and other crustal elements	100	200	*Near urban areas*	*Enclosing crushing, transfer areas* *Water spray suppression* *Chemical stabilization of unpaved traffic areas*	*Dependent on type of control and activity level of equipment; little data*
Pulverized Coal Boilers [1,4]	Ar, Cr, Hg, Mn, Ni, Pb, Sb, Se, V, Cl, and PM precursors (SO_x, NO_x)	*Unknown*	160	*Utility, mostly in rural areas* *Industrial, mostly near urban areas*	*ESPs, fabric filters*	*Capital cost, $50-110/kW; annual cost, 2-5 mils/kWh; total installed cost, $15-30/acfm*
Heavy Fuel Oil Combustion [1,5]	Cr, Fe, Ni, Pb, V, POM, Cl, PM precursors (SO_x, NO_x)	*≈30*	30	*Mostly in urban areas*	*Cyclones, ESPs*	*Unknown*
Residential Fuel Oil Combustion [1]	POM, PM precursors (NO_x)	*≈20*	20	*Mostly in urban areas*	*Proper maintenance, modern furnaces*	*Unknown*
Waste Incineration [1,6,7,8]	As, Be, Cr, Cd, Hg, Ni, Pb, PCDD/F, PCBs	*Unknown*	≈45	*Mostly near urban areas*	*Fabric filters, ESPs, venturi scrubbers*	*Total installed cost, $15-30/acfm*
Metal Smelting and Refining [1,9]	Cd, Cr, Pb, Zn, SO_x	*Unknown*	400	*Mostly in rural areas*	*ESPs, cyclones*	*Total installed cost, $15-30/acfm.*

APPENDIX 1 (con't). Overview of Current Knowledge of Risk Management of Fine Particles

[Numbers in regular type are typical values, selected from the referenced literature; entries in italics are estimates or judgments by ORD staff)]

Source Type [References]	Constituents of Concern	Total U.S. Emission Rate (10^3 tons/yr) $PM_{2.5}$ PM_{10}	Approximate U.S. Population in Close Proximity	Primary Control Options, Efficiencies for PM_{10}	Approximate Costs of Current Particle Controls
Outdoor Air Introduced into the Indoor Environment	Fine and coarse particles	Unknown	*≈250 million*	*Air cleaners for ventilation air (30-98%)*[b] *Whole-building air cleaners (30-98%)*[b] *In-room air cleaners (30-98%)*[b]	*Capital cost $3-$10/m³/h of outdoor Air treated; capital cost $1 to $10/m³/h of indoor air treated; $200-$800 per room*
Tracked-in dust	Lead, other heavy metals, pesticides	Unknown	*≈250 million*	*Cleaning (e.g., vacuuming) Whole-building air cleaners (30-98%)*[b] *In-room air cleaners (30-98%)*[b]	*No published data; capital cost $1-$10/m³/h of indoor air treated; $200-$800 per room*
Indoor Activities (that generate or resuspend particles)	Metals, microbials, pesticides	Unknown	*≈250 million*	*Source control, including maintenance* *Whole-building air cleaners (30-98%)*[b] *In-room air cleaners (30-98%)*[b]	*Highly variable; no data; Capital cost $1-$10/m³/h of indoor air treated; $200-$800 per room*

[a]Estimates of fine particle emissions from these "fugitive" sources, although large compared to other sources in this table, are very uncertain and need to be confirmed.
[b]Although the single-pass efficiency of air cleaners is generally known, their effectiveness in reducing exposures to indoor particles is not known.

REFERENCES

1. "The National Particulates Inventory - Phase II Emission Estimates," EPA Office of Air Quality Planning and Standards, June 1995, revised January 1996.
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3. "Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures." EPA 450/2-92-004.
4. Davison (1974), Kaakinen (1975), Klein (1975), White (1984), Markowski (1985), Kauppinen (1990), Andren (1975), Billing (1972).
5. Bulewicz (1974), Haynes (1978), Feldman (1982), Chung (1992).
6. Mumford (1986), Trichon (1989, 1991).
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8. Shen (1979), Bennett (1982), Dewling (1980).
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